Army Research Laboratory

A Procedure for Collecting Mental Workload Data During an Experiment That Is Comparable to IMPRINT Workload Data

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14. ABSTRACT

U.S. Army Research Laboratory (ARL) analysts use the Improved Performance Research Integration Tool (IMPRINT) to predict the mental workload and performance of Soldiers operating the Future Combat System (FCS) manned ground vehicles. IMPRINT is a human-performance-modeling tool that analysts use to build models representing Soldiers interacting with equipment to accomplish a mission. The models contain tasks, task sequences, task times, and workload estimates that allow the software to calculate estimates of mental workload and mission performance. One of the key outputs from the IMPRINT models is the combination of tasks likely to contribute to high Soldier workload. Evaluators of FCS equipment can include the potentially high workload task combinations into their evaluations to be sure that they evaluate the tasks mostly like to contribute to mental overload.

The U.S. Army Aberdeen Test Center (ATC) is one of the groups responsible for testing and evaluating FCS equipment and concepts. They must identify any issues that might degrade mission performance, including Soldier mental overload. To ensure that the ATC evaluations include tasks relevant to Soldier mental workload they can include high workload task combinations identified by IMPRINT into their test plans. However, to be compatible with IMPRINT, they must evaluate workload by a methodology compatible with the IMPRINT technique. This report outlines the methodology ATC and ARL developed within the Automated Communications Analysis of Situation Awareness /IMPRINT/Joint Warfighter Test and Training Capability test conducted in May 2008.

15. SUBJECT TERMS

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1. Introduction

One of the goals of human system integrators (HSI) is to design a system so the individuals operating it can do so with optimum effectiveness. A contributing factor to optimum effectiveness is the amount of mental workload an operator experiences while operating the system. HSI professionals consider an optimally designed system to result in evenly distributed manageable workload. Therefore, mental workload level is an indicator of optimum system design and a critical design parameter. Furthermore, it is a design parameter that should be considered early in the design process when problems detected are less expensive to correct and, therefore, more likely to be implemented. To achieve the goal of detecting mental workload issues early in the design phase, researchers at the U.S. Army Research Laboratory (ARL) have designed the Improved Performance Research Integration Tool (IMPRINT) (http://www.arl.army.mil/IMPRINT).

IMPRINT is a human performance modeling tool that provides HSI professionals with the capability of predicting the impacts of mental workload on the performance of the human operators of a system. Using IMPRINT, HSI professionals represent the operators of a system performing tasks with the system equipment to accomplish a set of goals. They estimate the mental demands these tasks impose upon the operators using numeric scales embedded within the tool. The IMPRINT software then predicts the overall workload of the operators of the system and identifies any potential high task combinations. When IMPRINT predicts that a particular set of tasks contributes to mental overload, system designers can make design changes to reduce the workload. Once they make the changes, analysts can model the system again in IMPRINT to see if they do indeed reduce workload. Eventually, however, the system designers will evaluate the system design within a laboratory or field test.

Because mental workload is a critical design criterion, when the developmental testers write their test and evaluation plan for a new system design, they should include an evaluation of the impacts of workload on performance within their test plan as criteria for system effectiveness. To achieve this goal, they can include in the plan the task combinations IMPRINT predicted would contribute to high workload and then evaluate the workload level and associated performance. To do this effectively, however, it is important that the evaluators and the IMPRINT analysts develop a procedure that ensures the test evaluates mental workload by a methodology comparable with the mental workload model within the IMPRINT tool. ARL and Aberdeen Test Center (ATC) researchers achieved this goal within the Automated Communications Analysis of Situation Awareness (ACASA)/IMPRINT/Joint Warfighter Test and Training Capability (JWTTC) experiment.

2. Objectives

The ACASA/IMPRINT/JWTTC test had several goals. The first and main objective was to collect voice communications data within a scenario that reflects the U.S Army Future Combat System (FCS) operational concept. SA Technologies researchers would then use this data to develop the ACASA tool. A second objective was to test the current iteration of JWTTC instrumentation. The last objective was to collect workload data compatible with IMPRINT workload predictions in order to verify IMPRINT analytical predictions and to enhance existing IMPRINT models of FCS crews. This report documents the final objective.

3. Methodology

3.1 Mental Workload

To compare the workload ratings from the ACASA/IMPRINT/JWTTS test with IMPRINT workload predictions, the researchers needed to collect workload ratings when the test participants were performing task combinations that would match task combinations that had predictions in already developed FCS IMPRINT models. This workload collection technique was required in order for the experiment to match the theory and technique IMPRINT uses to predict workload.

IMPRINT predicts workload based on Wickens' (1991) Multiple Resource Theory (MRT). According to MRT, human mental resources for handling tasks are limited. When an individual is required to perform multiple tasks at the same time, he or she is utilizing the same limited resources for the concurrent tasks. This combination of limited cognitive resources and multiple task demands may result in high workload that, in turn, may lead to a greater number of errors, increased task time, or both.

To build a MRT workload analysis in IMPRINT, analysts begin by building a task-network model to represent the functions and tasks individuals perform as they interact with the system to accomplish a set of goals called a mission. The model also includes the equipment or interfaces each individual uses for each task within the mission. Each interface, in turn, requires the individual using it to use one or more of four mental resources, visual, auditory, cognitive or psychomotor when completing a task. To quantify the amount of the mental resources each individual uses to complete each task with each interface, the analysts uses four behaviorally

anchored rating scales embedded into the IMPRINT tool (McCracken and Aldrich, 1984). Each of these scales represents one of the four different mental resources and provides the IMPRINT user with a consistent method for entering how much of each resource the human uses for each task he or she performs with each interface.

Throughout the mission, the individuals operating the system will use multiple interfaces and equipment to perform some tasks concurrently. To predict the workload across these multiple tasks, the IMPRINT software has an algorithm that aggregates the workload estimates the analysts selected for each task. The IMPRINT reports display this overall workload number for each individual each time a new task begins or ends in the mission. Mitchell (2000) provides a complete description of the workload approach in IMPRINT.

The ARL analysts used the IMPRINT workload approach to build a model to represent a basic set of functions and their associated tasks that the three Soldiers in the FCS mounted combat system (MCS) would perform. The functions included within this model were battle tracking, local security, communications (crew and higher headquarters), driving, target engagement and utilizing unmanned assets. Because the IMPRINT software calculates the workload for specific combinations of functions and tasks, the researchers conducting the ACASA/IMPRINT/JWTTC test needed to collect the workload data for a set of tasks similar to those in the functions of the IMPRINT MCS model. Collecting data from the similar sets of tasks would permit the ARL analysts to compare the test workload data to the IMPRINT predicted workload data for the same tasks. However, in addition to similar tasks, the workload measures collected during the test must indicate the level of workload the test participant was experiencing while performing the tasks. The researchers could then compare the collected workload ratings to the IMPRINT predictions. To meet this goal, the researchers selected multiple workload measures to collect workload levels during the experiment.

3.1.1 Workload Measures

Researchers typically use one or more of three types of measures to collect workload: subjective measures, physiological measures and performance-based measures. All of these were collected during the ACASA/IMPRINT/JWTTC experiment.

Subjective workload measures are “self-report” workload measures because with this technique individuals rate their own workload. The technique assumes that an individual can perceive the amount of effort they are using to complete one or more tasks. The researchers used a modified version of the Instantaneous Self Assessment (ISA) workload ratings (Kirwan et al., 1997) to collect workload during the experiment. The modified ISA scale has behaviorally anchored descriptions of varying levels of workload on a simple 1 to 5 scale. The experiment was paused several times in order to collect data for another tool, ACASA. During these pauses, the test participants gave ISA ratings. Table 1 shows the ISA scale used during the experiment.

Table 1. Instantaneous self-assessment of workload.

Circle how much workload you were feeling in your mind at the time the simulation was paused.
1 2 3 4 5
1 = Nothing to do. Rather boring.
2 = More than enough time for all tasks.
3 = All tasks going well. Busy but exciting speed of tasks. Could keep going always at this pace.
4 = Less important tasks suffering. Could not work at this level very long.
5 = Behind on tasks. Losing track of the full picture.

3.1.1.2 Physiological Workload Measures. One of the ATC test objectives was to develop physiological workload measurement techniques. Physiological measures assume that evaluators can assess mental workload by the individual's level of certain physiological measures such as eye tracking, electrocardiogram (EKG), electro-encephalogram (EEG), and galvanic skin response (GSR) measures. During the test, ATC evaluators instrumented two test participants and collected the EEG, EKG, and GSR data. They would use this data to identify times when the test participants' physiological data changed in response to events in the experiment. Once they knew what events triggered physiological changes, they could identify when these physiological changes indicated the participants were experiencing high workload to see if the high workload events matched the tasks in the IMPRINT workload predictions.

3.1.1.3 Performance-Based Workload Measures. The underlying assumption for performance-based measures of workload is that as a task becomes more difficult for a person to perform or as the person performs more simultaneous tasks workload increases. The higher the individuals' workload numbers are the more likely they are to experience performance problems due to workload. Performance-based workload measures collected during the test were designed by SA Technology researchers to assess the participants' awareness of the platoon situation at a specific time in the test. Specifically, at preplanned pauses in the simulation, the test participants recorded a number of key mission data points. For example, they identified the number of buildings the platoon's unmanned ground vehicle (UGV) entered; the number of IEDS the platoon encountered up to the current pause in the mission; the number of insurgent attacks the platoon encountered since the last pause. The SA Tech researchers compared their written answers to the actual data as indicators of performance. The IMPRINT analysts used these measures to indicate performance accuracy and compared them to the IMPRINT high workload predictions to see if performance declined during the task combinations for which IMPRINT predicted it would decline.

3.2 Situation Awareness Measures

During the ACASA/IMPRINT/JWTTS test, the SA Technology researchers collected performance on secondary tasks, such as dismount threats and SA questions. The test participants recorded this data during the pauses. It provided the SA Technology researchers with measures of situation awareness, mental workload, and performance. Effective response to a dismount threat was indicative of good situation awareness and reasonable workload, and was

evidence of good performance (Abounader et al., 2008). Slow or ineffective response to a dismount threat was indicative of poor situation awareness or cognitive overload, and was evidence of poor performance (Abounader et al., 2008). A quick, correct response to an SA probe was indicative of good situation awareness and reasonable workload, while an incorrect or non-existent response to an SA probe was indicative of poor situation awareness or cognitive overload (Abounader et al., 2008). A correct response was a predictor of good performance, while an incorrect response was a predictor of poor performance. ATC personnel integrated these measures into the scenarios, where they provided situation awareness, workload, and performance data for the SA Technology researchers, as well as, the ATC and IMPRINT researchers.

In addition to the performance-based SA measures, the SA Technology researchers collected subjective SA assessments using a post trial participant subjective situation awareness questionnaire (PSAQ) (Abounader et al., 2008).

3.3 Test Participants

Participants were six soldiers assigned to the test and evaluation group at ATC. The ATC researcher assigned each of the participants to one of two three-member teams. Each team represented the crew of an FCS MCS platform. One team represented the Platoon Leader's (PL) MCS and the other the Platoon Sergeant's (PSG) MCS. Table 2 displays the FCS MCS vehicles and player positions and roles. A role determines the information displayed to Soldiers so they can achieve the goals of a particular military position or job. Some positions consist of multiple roles because the Soldiers required informational needs for several roles.

Table 2. FCS MCS positions and roles represented in simulation.

MCS Vehicle 1		
Position	**Rank**	**FCS Roles**
Platoon Leader/Vehicle Commander	O1	Crewmember MCS Company Platoon Leadership Robotics Technician Vehicle Commander
Crew Chief	E5	Crewmember Robotics Technician
Driver	E4	Crewmember Driver
MCS Vehicle 2		
Position	**Rank**	**FCS Roles**
Platoon Sergeant/Vehicle Commander	E7	Crewmember MCS Company Platoon Leadership Robotics Technician Vehicle Commander
Crew Chief	E5	Crewmember Robotics Technician
Driver	E4	Crewmember Driver

The test participants represented MCS crews because ARL analysts had modeled the Platoon Leader's MCS vehicle in IMPRINT and made predictions on high workload task combinations. Thus, the analysts could compare the workload predictions for the MCS crews in IMPRINT with the MCS crews in the experiment. In order to compare the workload predictions from the model to those in the experiment, the participants had to perform experimental tasks similar to the IMPRINT model tasks.

3.4 Test Tasks

For the FCS MCS crew analyses, the IMPRINT analyses predicted battle tracking, local security tasks, utilizing unmanned assets, driving and communications would result in high workload when combined with standard mission execution tasks (Mitchell, 2005). Therefore, the test participants performed these tasks during the experiment. For the experiment, the researchers defined each of these tasks by specific observable behaviors and performance measures.

1. Battle Tracking.
    a. Building orders and graphics on display
    b. Watching current operations on display
    c. Looking at display for possible threats
    d. Marking target identification on display
    e. Looking at unmanned aerial vehicle location on display
    f. Looking at unmanned ground vehicle location on display

At specified times the test participant was required to identify and report certain pieces of information. Whether or not the test participant identified and reported the data correctly was the performance accuracy measure.

2. Fire Missions.
    a. Looking at display for possible threats
    b. Firing at line-of-sight target
    c. Firing beyond-line-of-sight mission
    d. Checking ammunition status
    e. Checking damage to target

ATC contract personnel recorded on video and ARL personnel recorded observational data on the targets identified, targets missed, false reports, number of line-of-sight missions, battle damage assessment reports, spot reports, and ammunition reports. Comparison of information in reports to correct information was the performance accuracy measure.

3. Monitoring communications within the MCS, between MCSs and from headquarters (voice communications).
    a. Listening for messages from company
    b. Hearing a voice message from company
    c. Sending a voice message to company
    d. Listening for voice messages from your platoon
    e. Hearing a voice message from your platoon
    f. Saying a voice message to your platoon
    g. Saying something to someone in your vehicle
    h. Listening to someone in your vehicle

Test participants must respond to voice messages addressed to their call sign. ATC contract personnel recorded on video, the number of times messages were sent/spoken before responses occurred. Accuracy of response was observed and recorded (accuracy measure is dependent on type of message).

4. Monitor unmanned assets.
    a. Reporting location of unmanned asset
    b. Looking at information from unmanned ground vehicle sensor
    c. Reporting location of unmanned aerial vehicle
    d. Looking at information from unmanned aerial vehicle
    e. Tele-operating unmanned ground vehicle
    f. Tele-operating unmanned aerial vehicle

The test participants must monitor the status of unmanned assets attached to the unit. Unmanned asset may be moving. Researchers asked the test participants the status of their unmanned asset.

5. Navigating.
    a. Maintaining route
    b. Driving
    c. Watching the driver's driving

ATC contract personnel recorded the number of crashes and driver behavior on video and ARL personnel recorded observational data.

3.5 Test Scenario

ATC and ARL personnel conducted the test in ATC building 400B. When the test participants arrived, the researchers gave an overview of the test and asked them to fill out informed consent forms and a demographic questionnaire. Next, the researchers assigned the participants to one of three player roles (table 2) and the participants practiced using the simulation in their assigned roles. On days 2 and 3 of the test, the participants performed eight trials (scenario runs) across two full 8-h days of data collection (refer to table 3). Data collection was continuous throughout the scenario runs. Day 4 was reserved for repeating any scenarios, if needed, and conducting an After-Action Review, which will include debriefing participants and answering any questions they have about the experiment.

Table 3. Daily test schedule.

Monday	Morning/Afternoon	Train participants on the simulation and their FCS roles
Tuesday	Morning	First and second mission threads
	Afternoon	Third and fourth mission threads
Wednesday	Morning	Fifth and sixth mission threads (VIP day)
	Afternoon	Seventh and eighth mission threads (VIP day)
Thursday	Morning	Repeat aborted or omitted mission thread if necessary, otherwise AAR
	Afternoon	AAR if not completed in the morning, otherwise nothing scheduled

Across the week of testing, the participants played the roles of MCS crews in four desert scenarios and four urban scenarios. A computer simulation represented each scenario and included a different type of mission as follows:

- Desert no. 1 – Detect IEDs on main supply route and secondary routes.
- Desert no. 2 – Find insurgents in specific villages; use UGV to search buildings as required
- Desert no. 3 – Surveillance of outdoor market; respond to suspicious activity
- Desert no. 4 – Locate weapons cache at night
- Urban no. 1 – Detect IEDs on urban roads
- Urban no. 2 – Clear buildings in specified area
- Urban no. 3 – Locate and follow a dismounted insurgent
- Urban no. 4 – Locate weapons cache at night

During the missions, the test participants collaborated using voice communication as well as interacting with events in the simulation. ATC personnel paused the simulation at specific times to allow testers to gather data.

3.6 Simulation

The simulation engine driving the test scenarios was based on UNREAL, a COTS first-person shooter computer game developed by Epic Games and Digital Extremes and published by GT Interactive (now owned by Atari) in 1998. ATC personnel modified the UNREAL simulation to meet the data collection requirements of this experiment. Specifically they modified the simulation to record the following to the log file:

1. Scenario events (e.g., injects, ‘actions’ of friendly and enemy units);
2. Participant inputs (e.g., button presses);
3. Every 30 s log output of vehicle and inject outcomes;
4. Ammunition use/levels during scenario;
5. Time-stamped events and participant inputs from the same, central reference clock’
6. Provided experimenter access to bird’s-eye view of map during scenario;
7. Provided out-the-window view for driver.

3.7 Data Collection

The IMPRINT analysts collected observational data of the Platoon Leader and Platoon Sergeant throughout the experiment. They documented in writing the major activities, communications, and times for these two positions. ATC personnel recorded on video the activities of the Platoon Leader and Platoon Sergeant. In addition, they recorded all voice communications and the physiological EEG, ECG and GSR measures for the platoon leader and platoon sergeant. During simulation pauses, the test participants completed performance measure queries related to situation awareness and gave ISA workload ratings. At the end of the experiment, they completed McCracken and Aldrich (1984) workload scales because these scales are the basis of the workload measures in IMPRINT. The simulation software logged the relevant scenario events, such as time of pauses, and participants’ actions, including use of controls and weapons. The simulation logged the location of the participants, enemies, unmanned vehicles, and weapons every 10 s to establish ground-truth. Additionally, all events, including the appearance of enemy threats and the firing of weapons, were logged and time-stamped. At the end of each scenario, the simulation generated summary data including total kills and shots fired.

Additionally, participants were video recorded. The primary purpose of video recording was to aid in debriefing or after action interviews. Additionally, the ATC researchers used the video recordings to help synchronize communication, physiological, and simulation data in the event that clock times and events did not line up properly.

4. Data Analysis

Tables 4–9 display the workload ratings from the ISA scale, the PSAQ ratings, and the functions performed by each test participant averaged across the pauses within each mission across the eight missions completed during the test.

Table 4. Platoon leader's self-report ratings and frequent functions performed across eight missions.

Mission	ISA	PSAQ: How Hard Working	PSAQ: How Well Performing	PSAQ: How Aware	Most Frequent Function
1	All tasks going well	Somewhat hard	Between average and very well	Between somewhat aware and very aware	Voice Communications Battle Tracking Fire Mission Unmanned Operations
2	All tasks going well then more than enough time for all tasks	Between not at all hard to somewhat hard	Between average and very well	Between somewhat aware and very aware	Voice Communications Fire Mission
3	More than enough time for all tasks	Somewhat hard	Between average and very well	Between somewhat aware and very aware	Voice Communications Battle Tracking Unmanned Asset Operations
4	All tasks going well	Between somewhat hard and very hard	Between average and very well	Between somewhat aware and very aware	Voice Communications Battle Tracking Fire Mission Unmanned Asset Operations
5	All tasks going well	Between somewhat hard and very hard	Average	Between somewhat aware and very aware	Not recorded
6	All tasks going well	Between somewhat hard and very hard	Average	Somewhat aware	Voice Communications Fire Mission
7	More than enough time for all tasks	Somewhat hard	Between average and very well	Between somewhat aware and very aware	Voice Communications Battle Tracking Fire Mission Unmanned Asset Operations
8	More than enough time for all tasks then all tasks going well	Between somewhat hard and very hard	Average	Somewhat aware	Voice Communications Fire Mission Unmanned Asset Operations

Table 5. Crew chief of the platoon leader's vehicle self-report ratings and frequent functions performed across eight missions.

Mission	ISA	PSAQ			Most Frequent Function
		How Hard Working	How Well Performing	How Aware	
1	More than enough time for all tasks then nothing to do	Somewhat hard	Between average to very well	Between somewhat aware and very aware	Voice Communications Fire Mission
2	Nothing to do	Not at all hard	Very well	Very aware	Nothing
3	No data	No data	No data	No data	No data
4	No data	No data	No data	No data	Fire Mission
5	All tasks going well	Somewhat hard	Very well	Very aware	Nothing
6	All tasks going well	Somewhat hard	Between average to very well	Between somewhat aware and very aware	Voice Communications Fire Mission Unmanned Asset Operations
7	Nothing to do	Not at all hard	Between average to very well	Between somewhat aware and very aware	Voice Communications Battle Tracking Fire Mission
8	Nothing to do then all tasks going well	Somewhat hard	Very well	Very aware	Voice Communications Fire Mission

Table 6. Driver of the platoon leader's vehicle self-report ratings and frequent functions performed across eight missions.

		PSAQ			
Mission	ISA	How Hard Working	How Well Performing	How Aware	Most Frequent Function
1	All tasks going well	Somewhat hard	Between average and very well	Very aware	Not collected
2	All tasks going well	Somewhat hard	Very well	Very aware	Not collected
3	Less important tasks suffering	Not at all hard	Average	Very aware	Voice Communications Battle Tracking Fire Mission
4	Less important tasks suffering then all tasks going well	Somewhat hard	Average	Very aware	Voice Communications
5	All tasks going well	Very hard	Between average and very well	Very aware	Nothing
6	All tasks going well then less important tasks suffering then all tasks going well	Somewhat hard	Average	Very aware	Voice Communications Battle Tracking Fire Mission Driving
7	Nothing to do then less important tasks suffering	Not at all hard	Average	Very aware	Voice Communications Battle Tracking Fire Mission Driving
8	All tasks going well	Very hard	Between average and very well	Very aware	Voice Communications Battle Tracking Fire Mission Driving

Table 7. Platoon sergeant's self-report ratings and frequent functions performed across eight missions.

Mission	ISA	PSAQ How Hard Working	PSAQ How Well Performing	PSAQ How Aware	Most Frequent Function
1	All tasks going well	Somewhat hard	Between average and very well	Between somewhat aware and very aware	Voice Communications Battle Tracking Fire Mission Unmanned Asset Operations
2	All tasks going well	Somewhat hard	Between average and very well	Between somewhat aware and very aware	Voice Communications Battle Tracking Fire Mission Unmanned Asset Operations
3	All tasks going well	Between somewhat hard and very hard	Average	Between somewhat aware and very aware	Voice Communications Battle Tracking Unmanned Asset Operations
4	All tasks going well	Somewhat hard	Between average and very well	Between somewhat aware and very aware	Voice Communications Battle Tracking Unmanned Asset Operations
5	All tasks going well	Between somewhat hard and very hard	Average	Between somewhat aware and very aware	Voice Communications Battle Tracking Fire Mission Unmanned Asset Operations
6	All tasks going well	Somewhat hard	Between average and very well	Between somewhat aware and very aware	Voice Communications Battle Tracking Fire Mission Unmanned Asset Operations
7	All tasks going well	Between not at all hard to somewhat hard	Average	Between not at all aware and somewhat aware	Voice Communications Battle Tracking Fire Mission Unmanned Asset Operations
8	All tasks going well	Between somewhat hard and very hard	Average	Between somewhat aware and very aware	Voice Communications Battle Tracking Fire Mission Unmanned Asset Operations

Table 8. Crew chief of platoon sergeant’s vehicle self-report ratings and frequent functions performed across eight missions.

Mission	ISA	PSAQ			Most Frequent Function
		How Hard Working	How Well Performing	How Aware	
1	More than enough time for all tasks then nothing to do	Not at all hard	Average	Between somewhat aware and very aware	Voice Communications Fire Mission
2	Nothing to do	Not at all hard	Very well	Between somewhat aware and very aware	Fire Mission
3	More than enough time for all tasks	Between not at all hard to somewhat hard	Very well	Between somewhat aware and very aware	Not recorded
4	All tasks going well	Between not at all hard to somewhat hard	Very well	Between somewhat aware and very aware	Not recorded
5	More than enough time for all tasks to all tasks going well	Somewhat hard	Average	Between somewhat aware and very aware	Not recorded
6	More than enough time for all tasks to all tasks going well	Somewhat hard	Average	Between somewhat aware and very aware	Not recorded
7	Nothing to do then all tasks going well	Between not at all hard to somewhat hard	Between average and very well	Between somewhat aware and very aware	Not recorded
8	All tasks going well	Between somewhat hard and very hard	Between average and very well	Between somewhat aware and very aware	Voice Communications Fire Mission

Table 9. Driver of platoon sergeant's vehicle self-report ratings and frequent functions performed across eight missions.

Mission	ISA	PSAQ			Most Frequent Function
		How Hard Working	How Well Performing	How Aware	
1	Nothing to do	Not at all hard	Very well	Very aware	Driving
2	Nothing to do	Not at all hard	Very well	Very aware	Driving Fire Mission
3	More than enough time for all tasks then nothing to do	Not at all hard	Very well	Very aware	Voice Communications
4	More than enough time for all tasks	Not at all hard	Very well	Very aware	Nothing
5	More than enough time for all tasks then all tasks going well	Not at all hard	Average	Very aware	Nothing
6	More than enough time for all tasks then nothing to do	Not at all hard	Average	Very aware	Voice Communications
7	Nothing to do	Not at all hard	Average	Very aware	Nothing
8	More than enough time for all tasks	Not at all hard	Average	Between somewhat aware and very aware	Nothing

As tables 4–9 show, the primary function performed by all players throughout the test was voice communications. Therefore, table 10 shows the communications frequency throughout the test by player.

In addition to the completing the communications data analysis results in table 10, the researchers compared the times for the voice communication data collected during the experiment and the speech micro-model predictions in IMPRINT. In order to perform this comparison, they counted each word from the voice messages in all eight missions. They then used to the word counts to calculate the predicted verbal communications in IMPRINT. Finally, they compared the times from the test data to the IMPRINT predictions to determine the relationship, if any, that existed between the two data sets. The relationship between actual voice communication (as measured by the Mission_Time) and predicted voice communication (as measured by the IMPRINT_Time) was investigated using the Pearson product-moment correlation coefficient. The analysts found that there was a strong, positive correlation between the two variables [$\underline{r} = 0.649$, $\underline{n} = 3874$, $\underline{p} < 0.0005$]. They calculated the correlation using SPSS v.15. Table 11 shows the results of the calculation.

Table 10. Communication duration and frequency by position.

POSITION	CO	PL	PLG	PLD	PSGT	PSGG	PSD	All
CO								
Mean (milliseconds)		5972	1125	955	7170	689	4031	7443
No. of Msgs.		41	<1	<1	28	5	5	22
PL								
Mean (milliseconds)	8808		4655	9780	9122	661	8526	7714
No. of Msgs.	50		15	22	16	1	8	19
PLG								
Mean (milliseconds)	542	4043		2797	0	1219	1382	2991
No. of Msgs.	<1	20		23	0	<1	1	6
PLD								
Mean (milliseconds)	510	6574	4884		0	622	695	6657
No. of Msgs.	1	29	16		0	<1	1	6
PSGT								
Mean (milliseconds)	3052	4190	0	0		2172	3359	5071
No. of Msgs.	34	17	0	0		4	18	8
PSGG								
Mean (milliseconds)	1664	2720	0	452	3893		3288	3143
No. of Msgs.	2	1	0	<1	7		9	2
PSGD								
Mean (milliseconds)	2919	2787	1734	1659	4392	3519		2181
No. of Msgs.	1	8	1	24	17	0		5

Table 11. Correlation between IMPRINT speech model times and test data.

		Mission_Time	IMPRINT_Time
Mission_Time	Pearson Correlation	1	0.649[a]
—	Sig. (2-tailed)	—	0.000
—	N	3875	3874
IMPRINT_Time	Pearson Correlation	0.649[a]	1
—	Sig. (2-tailed)	0.000	—
—	N	3874	3874

[a]Correlation is significant at the 0.01 level (2-tailed).

4.1 Discussion of Results

4.1.1 Overview

The data analysis in this report focused on the ARL researchers' observational data, the ISA ratings, and SA ratings. SA Technology researches and ATC physiological researchers are analyzing their own data sets respectively.

The collection of voice communications for the ACASA tool was the primary test objective. To meet this objective, the test designers had intentionally developed a scenario that would generate frequent voice message traffic. For example, although FCS vehicles and dismounts have digital communications capability, the test participants communicated by voice. Therefore, as tables 4–9 show, sending and responding to voice message traffic either alone or in combination with other tasks became the most frequent mission task performed by most of the test participants. Although the primary test objective may have influenced the rate of voice communications, communications monitoring and responding are tasks performed frequently by FCS vehicle crews and dismounted Soldiers. For this reason, these tasks are included in every IMPRINT model the ARL researchers have built to represent FCS platform crews and dismounted Soldiers. Therefore, the ARL researchers were able to compare some of their IMPRINT predictions related to communications tasks with the test data.

In the analysis of the results from their FCS models, the ARL researchers had predicted that combining communications tasks with other tasks would increase workload to a level that would contribute to decrements in the FCS Soldiers' performance (Mitchell and Brennan, in review; Mitchell, 2005). Observational data results from the ACASA experiment are consistent with the IMPRINT predictions. For example, in the ACASA experiment, the platoon leader experienced communications performance decrements when he combined communications tasks with battle tracking. Specifically, he missed a grid location given out in the voice message because he was already trying to locate a grid on the map. He gave the incorrect grid coordinates to his platoon and missed another voice message while trying to determine the correct grids. He delayed responding to a message from the company commander when he was tracking items on the map.

Although the test results for performance on communications tasks appear to be consistent with IMPRINT predictions, the ARL researchers did not have enough ISA workload ratings to correlate the workload ratings from the test with the workload predictions from their IMPRINT FCS models. To compare the workload predictions from their FCS IMPRINT analyses with the test data, the ARL researchers needed to know what task combinations the test participants were performing when they gave a workload rating. This data was not available. The primary objective of the test was to collect voice communications data within a scenario that reflects the FCS operational concept for development of the ACASA tool. To meet this objective the SA Technology researchers needed SA and performance data collected that required pausing of the simulation. The test designers decided that the test participants would do the ISA workload ratings during the pauses as well. The rationale for this decision was to ensure that the ACASA data which was the primary test goal was unaffected by the IMPRINT data collection needs which were a secondary test objective. The IMPRINT data collection would have required the test participants to give more frequent workload ratings. The IMPRINT analysts needed more frequent workload ratings because they needed to identify how workload ratings varied with specific task combinations. Because of this decision, the IMPRINT analysts had difficulty in the data analysis determining which specific task combinations correlated with the Soldiers' workload ratings. To meet this challenge, the analysts reviewed their observational data and identified which broad task categories or functions, each crewmember performed in the time interval prior to a scheduled simulation pause. They then paired an ISA workload rating given during the pause in the simulation required for ACASA data collection with the functions in the interval prior to the pause.

4.1.2 Platoon Leader Functions and Workload Ratings

The specific tasks the platoon leader performed across the eight missions were various combinations of voice communications, battle tracking, fire mission tasks, and unmanned asset operations. Across the eight missions in the test, the platoon leader reported via his ISA ratings that his workload level "permitted more than enough time for all his tasks" and that "all tasks were going well." For the PSAQ, he reported he was working "somewhat hard to very hard" while performing these tasks for most of the missions. He thought this effort resulted in "between average to very well performance" with "somewhat to very aware situation awareness ratings" on most missions. The platoon leader's workload ratings, unlike the IMPRINT predictions, indicate his workload level was not high during the missions. However, his performance was consistent with the IMPRINT performance predictions of a performance decrement. For example, although he reported his performance for the first mission was "average to very well," he did experience performance errors while monitoring voice communications concurrent with battle tracking. Specifically he missed a grid location given out in the voice message because he was already trying to locate a grid on the map. He gave the incorrect grid coordinates to his platoon and missed another voice message while trying to

determine the correct grids. He delayed responding to a message from the company commander when he was tracking items on the map. These errors are consistent with IMPRINT model predictions (Mitchell and Brennan, in review; Mitchell, 2005) of the impact of communications tasks on battlefield awareness.

4.1.3 Platoon Leader Vehicle Crew Chief

In comparison to the platoon leader's workload ratings, his crew chief's overall workload ratings were lower. The crew chief participated in six of the eight missions. For four of the six missions he participated in, he reported that he had "more than enough time for all tasks" or that he had "nothing to do" for all or parts of the missions. During these four missions, he was doing fire mission and communications tasks. The fire mission tasks consisted mainly of searching for potential targets. These tasks are the primary tasks typically performed by gunners of combat platforms and are included in the IMPRINT models for the FCS mounted combat system. In the ARL researchers analysis of the MCS models (Mitchell, 2005; Mitchell et al., 2003) they predicted the gunner to have the lowest workload because his primary function is to scan for targets. This prediction is consistent with the gunner's ISA rating for low workload and nothing to do.

For his first mission the crew chief reported he had "more than enough time for all tasks" prior to the first pause and "nothing to do" after the second pause. "Nothing to do" was his rating for missions 2, 7, and 8 as well. In contrast to the other four of his missions, the PLV crew chief reported that for two missions all of his "tasks were going well." For these two missions he did the same tasks as the other four but, in addition, he controlled the unmanned ground vehicle. Therefore, the unmanned asset control, probably accounts for the higher self-report workload rating.

Similar to his workload ratings that were lower than the platoon leader's ratings, the crew chief rated his level of effort during his missions as lower than the platoon leader's. Across the six missions, he reported he worked "not at all hard" to "somewhat hard." Although his reported level of effort was lower than the platoon leader's, he perceived his performance to be between "average and very well" and he was reportedly "somewhat" to "very aware" of the situation. Therefore, he rated his perceived performance and awareness as consistent with the platoon leader's self-reported ratings of these two categories. During these missions, the ARL researchers recorded that he neutralized a target without permission from the company commander. On the other hand, they recorded that he assisted the platoon leader by correcting incorrect grids the platoon leader was reporting. The first observation indicates he was not performing well or aware of the situation because he should have waited for the company commander's permission. On the other hand, the second observation indicates that he was more aware of the correct grids than his platoon leader and performing very well and very aware. SAGAT data SA Tech is analyzing will provide further insight on the actual performance level of the crew chief during his missions.

4.1.4 Platoon Leader Vehicle Driver

The ISA ratings the driver of the platoon leader's vehicle gave for his missions fluctuated between "all tasks going well" and "less important tasks suffering." There is no obvious pattern in the observational data in table 6 that explains the variations in his workload ratings. However, that maybe a reflection of the lack of actual driving required by the scenario. The driver did not have to drive the vehicle often during the scenario. Instead, he participated in voice communications and assisted with battle tracking and fire missions. He did not need to move the vehicle because the platoon leader could move the unmanned ground vehicle to do reconnaissance rather than moving his own vehicle. Mission 8 was the mission during which the driver actually drove the vehicle most frequently. This mission had a consistent workload rating which of "all tasks are going well." Whereas, for most of the missions, he reported his level of effort as "somewhat hard," for Mission 8, he rated his level of effort as "very hard." He rated his performance during this mission as between "average" and "very well" and reported he was "very aware" of the situation. The ARL analysts recorded that at times he was spinning the vehicle in circles to relieve boredom. There was no other observable pattern to his performance and ratings.

4.1.5 Platoon Sergeant

In addition to the traditional platoon sergeant functions, the platoon sergeant controlled and monitored the unmanned aerial vehicle throughout the test. The traditional functions included functions similar to the other positions in the test. Specifically, he performed battle tracking, fire missions, and voice communications. His workload rating remained consistent across all eight missions with him reporting, "All tasks are going well." He rated his level of performance as "somewhat hard" to "between somewhat hard" and "very hard" for most of the missions. Mission 7, however, had a lower level of effort rating of between "not at all hard" to "somewhat hard." Indeed, the ARL researcher noted that he fell asleep during this mission and this observation supports his reported lower level of effort. Despite the fact he had fallen asleep during this mission, he rated his performance as "average." In addition, he rated his performance as "average" to between "average" and "very well" across all eight missions. He rated his awareness as between "somewhat aware" and "very aware" for all missions except mission seven during which he fell asleep. For this mission, he rated his awareness as between "not at all aware" and "somewhat aware." The ARL researchers observed him falling asleep, which supports his rating of lower awareness of the situation.

In addition, to their observations of the platoon leader falling asleep, the ARL researchers noted that he had difficulty monitoring the UAV when he conducted battle tracking. Specifically, either he located something on the map on his display or he monitored the flight of the UAV. They had observed similar alternation of tasks by a platoon sergeant during the Omni Fusion 06

test at Fort Knox. During this test, the platoon sergeant either completed battle tracking tasks or monitored an unmanned armed reconnaissance vehicle but could not do both concurrently (Mitchell, 2007).

In addition to having difficulty battle tracking while monitoring the UAV, the ARL researchers observed other instances where the platoon sergeant seemed to have reduced situation awareness while controlling the UAV. Specifically, he did not notice that one of the platoon members was driving his vehicle over a simulated unmanned vehicle, he missed a threat that appeared in front of the vehicle, and he missed an IED. In addition, they observed that he made several communications errors that included missed communications from the company commander and platoon leader, using the incorrect call signs when sending communications, missing part of an order, missing grid coordinates, and missing a target engagement message. In mission 7, during which he was falling asleep, the company commander had to notify him that he did not have the UAV on the IED as ordered by the commander. During the next mission, he crashed the UAV into a tree, used the incorrect call signs and was late to respond to messages from the commander. His observed performance contradicts his self-reported workload ratings of all tasks going well, as well as, his performance and awareness ratings. Falling asleep, communications problems, and unmanned asset control problems do not represent average to very well performance or between somewhat aware and very aware. Because he fell asleep during the simulation, it is possible that the observed performance decrements were due to task underload rather than overload. On the other hand, most of the errors occurred when he was performing unmanned asset operations concurrent with other tasks which indicates that unmanned asset operations was contributing to overload.

4.1.6 Platoon Sergeant Vehicle Crew Chief

Similar to the crew chief in the platoon leader's vehicle, the crew chief in the platoon sergeant's vehicle acted as gunner and performed primarily voice communications and fire mission related tasks. He reported "all tasks were going well" and that he had "more than enough time" or "nothing to do" for most of the missions. He reported his level of effort varied between "not at all hard" to between "not all hard" and "somewhat hard" for the majority of the missions. For two missions he reported he worked "somewhat hard." He rated his performance as either "average" or "very well" except for two missions for which he rated his performance as between these two ratings. His awareness of the situation he rated as between "somewhat aware" and "very aware" for all eight missions. The ARL researchers observed his behavior for only two of the eight missions. During these two missions, they noted that he seemed bored as exhibited by his scanning the same place throughout the mission.

4.1.7 Platoon Sergeant Vehicle Driver

The driver of the platoon sergeant's vehicle performed driving and voice communications as his most frequent functions. However, the platoon sergeant's vehicle did not move often during the test. Some of the driving tasks the driver performed consisted of moving the vehicle back and

forth in the same place. Reflecting his low level of activity, the driver rated his workload as "nothing to do" or "more than enough time for all tasks." Similarly, he rated his level of effort as "not at all hard" for all eight missions. Although he was not doing a lot, he rated his performance as "very well" for the first five missions and "average" for the last three missions. Furthermore, for all but the last mission, he rated himself as "very aware of the situation." For the last mission, he rated himself as between "somewhat aware" and "very aware." The ARL researchers did not record any performance errors for him.

4.1.8 Communications Data Analysis

Because the collection of voice communications for the ACASA tool was the primary test objective, there was detailed voice data available for analysis. This voice data included verbatim all the voice communications from the test. From this voice data transcription, the ARL researchers calculated the number of messages each platoon member sent to another platoon member and the length of each of theses messages as shown in table 10. They can use this message data in IMPRINT models to provide estimates of voice traffic within a platoon that does not have digital capability.

In addition to calculating the frequency and times of messages with the platoon, the ARL researchers correlated the IMPRINT times predicted for a platoon member to speak a message with the actual test times for the spoken messages as shown in table 11. By squaring the r-value (0.649) from the correlation, they could calculate the coefficient of determination. This value is useful in explaining how much variance the two data sets share as the percent of variance in the dependent variable explained by the independent. The value from this test, 0.649 squared, indicates 42.25% shared variance between actual and predicted voice communication times. This percentage indicates correlation between the analytical predictions of the IMPRINT speech micro-model and the test data. They also noticed the high usage of short sentences using one to seven words throughout the experiment. This indicates that soldiers prefer concise verbal communications rather than longer ones during combat operations. Soldier subject matter experts have reported to the ARL researchers that they prefer short communications and this data confirms their report. Based on this test data, IMPRINT analysts can select workload ratings for one or two words as inputs for communications tasks.

5. Conclusions and Recommendations

The researchers who participated in this test had several concurrent objectives to achieve. Unfortunately, the criteria necessary to satisfy the primary objective, collecting voice data, interfered with data collection for the secondary objectives, verifying workload predictions.

Specifically, throughout the test, the test participants were giving self-report workload, level of effort, performance, and awareness ratings. By definition, self-report ratings are an individuals own estimate and are subjective. To verify these ratings, researchers need to know what the individuals were doing when the individuals gave the ratings and the actual performance of the individuals. During this test, however, the test participants gave their self-report ratings during pauses when it was unclear what they had been doing prior to the pauses. The ARL researchers written observations describe what the test participants were doing in the segment prior to the rating. However, because what they were doing changed throughout the segment but the test participant gave only one self-report rating, it is unclear what activities correlated with the ratings. Therefore, the researchers recommend that subsequent experiments have workload data collection as a primary objective.

With workload data collection as a primary objective, the researchers could make sure that the workload ratings correlate with Soldier activities. They could do this by developing a scenario that controls the activities the Soldiers performed at specific times. For example for a three-Soldier MCS crew, a segment of the scenario could consist of driving from one checkpoint to another checkpoint. During this segment, the driver drives the vehicle, the crew chief scans for threats, and the commander battle tracks. When the scenario is paused and an ISA rating given, the researchers would know the major functions each Soldier was performing prior to the pause. To vary workload throughout the scenario, the researchers could add functions to this basic set of drive, scan, and battletrack to other segments and obtain workload ratings. For example, another segment of the scenario could have the vehicle moving from one checkpoint to another checkpoint while monitoring an unmanned robotic vehicle. The driver drives, the crew chief scans for threats and monitors the unmanned vehicle and the commander battle tracks. Following this procedure, the researchers could compare the crew chief's workload ratings from each segment and attribute any differences to the addition of unmanned vehicle monitoring.

Creating scenario segments of Soldier functions will permit better assessment of workload but to connect these workload ratings to performance, the researchers will need to add performance metrics to each segment as well. For example, they can assess the driver's deviation from the route in each segment or the number of targets identified by the crew chief, or the commander's correct identification of friendly locations and unmanned asset interventions as performance metrics. These performance metrics permit the researchers to correlate any changes in workload levels across segments to changes in performance.

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